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ASSOCIATION BETWEEN ROOT TRAITS AND DROUGHT TOLERANCE UNDER INTERMITTENT DROUGHT STRESS CONDITIONS IN GROUNDNUT (ARACHISHYPOGAEA. L)

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ABSTRACT

Root traits along with physiological traits are needed to better dissect the drought tolerance. A study was conducted at UAS, Dharwad to evaluate the RIL population developed from parents TMV-2 (drought susceptible) and GM 6-1 (drought tolerant) for root and physiological traitsunder intermittent drought conditions and to dissect their correlated response towards pod yield. Pod yield per plant under water stress (WS) condition showed significant positive correlation with root length, root to shoot ratio, relative water content at 30 DAS and SPAD chlorophyll meter reading while it had significant negative association with per cent reduction in RWC from 15 to 30 DAS, per cent reduction in RWC from 7 to 30 DAS, specific leaf area at 15 DAS and specific leaf area at 30 DAS during both the seasons of summer 2012-13, summer 2013-14.Root length under WS condition showed significant positive correlation with root to shoot ratio, root dry weight, relative water content at 30 DAS and SPAD chlorophyll meter reading while it had significant negative association with per cent reduction in RWC from 7 to 15 DAS, per cent reduction in RWC from 15 to 30 DAS, per cent reduction in RWC from 7 to 30 DAS and specific leaf area at 30 DAS during both the seasons of summer 2012-13, summer 2013-14.Root traits such as root length and root to shoot ratio while, physiological traits such as RWC, SLA and SCMR during severe drought conditions could be effective selection criteria for improving the pod yield in groundnut under intermittent drought conditions where substantial amount of water are left in the subsoil after vegetative phase.

KEYWORDS: Dharwad, Chlorophyll, RWC, SLA and SCMR

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Original Article

INTRODUCTION

Drought is by far the most important abiotic stress contributing to crop yield loss in the semi-arid tropics (SAT) characterized by low and erratic rainfall. More than half of the production area, that accounts for 70 per cent of the groundnut growing area fall under arid and semi-arid regions, where crop is frequently subjected to drought stresses for different duration and intensities (Reddy *et al*., 2003). Unpredictable and intermittent periods of water deficit commonly occur during its growth period (Vorasoot*et al*., 2003).Effect of drought on yield is highly dependent on the stage when the stress occurs and the available water to the crops at that stage (Ratnakumar*et al.* 2009). Water uptake is crucial during key stages like flowering and kernel filling (Boyer and Westgate 2004) where yield reductions of 56–85 per cent were recorded when groundnut was exposed water stress at these stages (Del Rosario and Fajardo, 1988) and small differences in water uptake can bring large yield benefits in groundnut (Boote*et al*., 1982; Ratnakumar*et al*., 2009). Therefore, breeding for drought

adaptation is an important strategy in alleviating drought effects on groundnut productivity.

Roots could play an important role for yield increase in response to drought in groundnut as roots are the very place where plants first encounter drought stress and able to sense and respond to the stress condition. But the information on the responses of root characteristics of diverse groundnut genotypes to intermittent drought under field conditions is still lacking and further investigations are necessary. Further, the mechanisms underlying yield responses of the groundnut genotypes have not been well understood because there was no information on root traits under these conditions.

Both yield and drought tolerance cannot be considered as a single trait. Hence the response of yield to drought condition may not distinctly be explained by the responses of rooting traits alone without considering their association with physiological response of the genotype. Several studies have reported on the response of physiological characters concerning with increased yield after drought stress such as Relative Water Conrent (RWC), Specific Leaf Area (SLA) and SPAD Chlorophyll Meter Reading (SCMR) (Nautiyal et al., 1999; Painwadeeet al., 2009 and Jongrungklang*et al*. (2011)). However, those reports were limited to experiments under greenhouse conditions and with only a few genotypes anddid not reveal the relationship between the physiological and rooting characters for contributing to pod yield under intermittent drought stress. There is an immediate need to study the mechanism of response of root traits along with physiological traits for the pod yield under drought stress in field conditions. Based on these cited facts, it was proposed in this study to evaluate groundnut RIL population for root and physiological traits and their correlated response to pod yield under irrigated and water stress conditions.

MATERIAL AND METHODS

Experimental Material

The experimental material for the present study consisted of RILs in F_8 generation derived from the TMV-2 x GM 6-1 cross. A total number of 299 RILs were available for present study, which were evaluated along with the parents and eight checks.

Meteorological Conditionsand Soil Moisture Content

Rainfall, relative humidity (RH), maximum and minimum temperature were recorded daily from sowing until harvest at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad at a distance of 100 m from the experimental field.Soil moisture content was determined using gravimetric method at stages *viz.*, 30, 45, 60 and 75 DAS and at final harvest at depths of 0–15, 15–30 and 30–45 cm to verify level of moisture content in well watered (WW) and water stress (WS) treatments.

Phenotyping for Physiological Traits and Pod Yield

The RIL population in F_8 generation developed out of the two genotypes *viz.*, TMV-2 and GM 6-1 with distinct difference in root length and physiological traits under water stress condition along with the parents and checks were phenotyped for pod yield and physiological traits under well watered as well as water stress conditions during summer seasons of 2012-13 and 2013-14.

A factorial experiment was planned in a randomized complete block design (RCBD) with two replications. The two water regimes of Well Watered (WW) and Water Stress (WS) conditions were assigned as Factor A, whereas the genotypes (2 parents + 299 RILS + 8 checks) were considered as Factor B. All the entries were sown on 15-02-2013 during

summer season of 2012-13 and on 06-01-2014 during summer 2013-14. In both the seasons sowing was done in one row of 1m length with a spacing of 30 cm between rows and 10 cm between the plants. The recommended packages of practices were followed for raising a good crop.

Management of Irrigation for Treatment Application under Field Condition

The plants were exposed to intermittent stress in the WS plot from the time of flowering (on 21-03-13 during summer 2012-13 and on 16-02-2014 during summer 2013-14) until pod initiation stage (on 28-04-2013 during summer 2012-13 and on 20-03-2014 during summer 2013-14) in field. In the field drought stress was imposed by irrigating both the plots (WW and WS) equally upto the time of flowering. Imposition of stress was initiated after the flowering for WS plot while, irrigation was supplied to the WW plot at 7-10 days interval. Irrigation to the WS plot was supplied based only when the wilting score of a majority of WS plots reached a value of 4. The scoring of wilting symptoms was recorded on a visual score of 1-5 where, 1 = no wilting symptoms, score 2 = few leaves wilted in a few plants from the plot, score 3 = a majority of plants in a plot have wilted leaves, but none has reached permanent wilting, score 4 = few of plants show at least partial symptoms of permanent wilting and score 5 = most plants show symptoms of permanent wilting (Ratnakumar*et al*., 2009). Harvesting was done in both the plots at physiological maturity stage.

Phenotyping for Root Traits

Phenotyping of RILS along with parents and checks for root traits was being carried out under well watered as well as water stress conditions during two seasons of summer 2012-13 and summer 2013-14. A raised bed (1.5 m height) of 5 m x 3 m with 28 rows was used, where sowing was done to accomplish one seedling per hill for each accession on the raised bed. The seeds were sown on 26-02-2014 and 02-01-2014 during summer 2012-13 and summer 2013-14 respectively. All the entries were sown with a spacing of 20 cm between the rows and 10 cm with in the row.

During summer 2012-13, all the entries (2 parents + 299 RILS + 14 checks) were laid out in an augmented design (Federer, 1956, 1961, 1991) with two blocks and 14 checks. Entries are assigned to these plots in the form of an incomplete block design. During summer 2013-14, a factorial experiment was planned in a randomized complete block design (RCBD) with two replications. The two water regimes of WW and WS conditions were assigned as Factor A, whereas the genotypes (2 parents + 299 RILS + 8 checks) were considered as Factor B. The recommended packages of practices were followed for raising a good crop.

Management of Irrigation for Treatment Application under Raised Bed

In the raised beds, both WW and WS conditions were fully irrigated until flowering time (on 24-03-2013 and 05-02-2014 of summer 2012-13 and 2013-14 respectively) by supplying a constant amount of water on daily basis. During imposition of stress, WS condition was maintained as rain out shelter to protect from rain. Similar scoring of wilting symptoms as used in field condition was followed to supply irrigation in the WS condition when the wilting score was severe in WS plots. Harvesting of the individual plants in both blocks for recording of root traits was done at 75 DAS during first season while in the second season harvesting was done at 90 DAS sowing. Plants were thoroughly washed manually with tap water to remove the soil and debris for recording the root traits.

Recording of Observations

Soil Moisture Content

Average soil moisture from 0 to 15 cm was measured by using a micro auger at different stages of estimating RWC. Soil sample of about 50-100 gm was collected and weight of the soil was recorded as wet weight. Sample was placed in the oven at 8^0C for 24 hours. Weight of the dried soil sample was recorded as dry weight.

The moisture content in dry weight basis can be calculated using the following formula (Black 1965).

$$\text{Soil moisture content (\%)} = \frac{\text{Wet weight of the soil (gm)} - \text{Dry weight of the soil (gm)}}{\text{Dry weight of the soil (gm)}} \times 100$$

Root Traits

The root traits such as root length and root to shoot ratio of each plantwererecorded at final harvest. Root samples were washed manually with tap water to remove soil and debris for determining root length per sample. Root samples were oven-dried at 80 °C for 48 h or until constant weight and root dry weight (RDW) was determined.

Pod Yield Per Plant

At the final harvest, pod yield was obtained from all the plants in each treatment

Physiological Traits

Relative Water Content (RWC)

RWC was recorded during both seasons at three stages *viz.*, 7, 15 and 30 days after stress (DAS). Ten plants in each plot were randomly chosen and the second fully expanded leaves from the top of the main stems were used for determination of relative water content. Leaf discs of one cm diameter were punched and fresh weight (FW) was recorded. The leaf disc samples were then soaked in distilled water for 4-5 hrs and blotted for surface drying and water saturated leaf weight was determined as turgid weight (TW). The samples were oven-dried at 80 ^{0}C until reaching constant weight and leaf dry weight (DW) could be determined. RWC was calculated based on the formula suggested by Gonzalez and Gonzanlez-Vilar (2001) as follows.

$$\text{RWC (\%)} = \frac{\text{Fresh weight - Dry weight}}{\text{Turgid Weight - Dry Weight}} \times 100$$

Specific Leaf Area (SLA)

For recording of SLA, the second fully expanded leaves were detached from the ten chosen plants were in kept in butter paper bags for recording observations. Leaf discs were punched from the selected leaves and leaf area was measured. Leaves were dried in an oven at 80°C for at least 48 h to determine the leaf dry weight. Immediately after drying, the leaves were weighed and the SLA was derived as leaf area per unit leaf dry weight (cm2 g–1). The SLA was calculated using the following formula (Evans, 1972).

$$SLA = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Leaf dry weight (g)}}$$

SPAD Chlorophyll Meter Reading (SCMR)

The SPAD chlorophyll meter (Minolta SPAD-502 m, Tokyo, Japan) reading was recorded on each leaflet of the tetrafoliate leaf of five selected plants along the midrib.

Statistical Analysis

ANOVA was performed for all the physiological traits and pod yield per plant in each year and root traits in summer 2013-14 according to factorial design (Windostat 9.1) whereas ANOVA for root traits during summer 2012-13 was performed according augmented design (Windostat 9.1).

RESULTS AND DISCUSSIONS

Meteorological Conditions and Soil Moisture Content

Geographically, Main Agricultural Research Station, Dharwad is located at a latitude of 15°12^1 N of 75°07^1 and an altitude of 678 m above mean sea level. It received an average rainfall of 740.40 mm in the year 2013 with one peak in June-July and 887.20 mm in 2014 with one peak two peaks in June-July and another in August-September. About 97.60 mm of total rain fall received in summer 2012-13 (February-May) while rainfall received was 108.10 mm during summer 2013-14 (January-April). The mean temperature varied from 19.45°C to 40.89°C in 2013 and 19.50°C to 30.70°C in 2014. The relative humidity recorded in 2013 was highest with 96.50 per cent during the month of July and the lowest of 29 per cent during the month of April. It ranged from 31 to 97 per cent in the year 2014. Variation with respect to mean daily temperature (^{o}C), relative humidity (%) and rainfall during crop growth periods of field and raised bed evaluation of summer 2012-13 and summer 2013-14 are depicted in the Figure 1a, 1b, 1c and 1d.

The soil water content of two water regimes in both raised bed and field condition showed clear differences during both seasons of summer 2012-13 and 2013-14. Soil water content under drought conditions decreased from stage of drought stress imposition to pod filling stage compared to non-stress treatment (Figure 2a and 2b), indicating that water stress was sufficient to simulate the intermittent drought conditions in both raised bed as well as field conditions.

ANOVA for Root Traits

During summer 2012-13 all the genotypes included in the study differed significantly for all traits studied in each season (Table 1). Effects of entries, checks, varieties and the interaction effect of checks * varieties were significant for most of the traits studied under both well watered and water stress conditions. During summer 2013-14, all genotypes included in the study differed for all traits in each season (Table 2). Irrigation level (well watered and water stress conditions) and Genotypes * irrigation level had significant effect on all the traits studied.

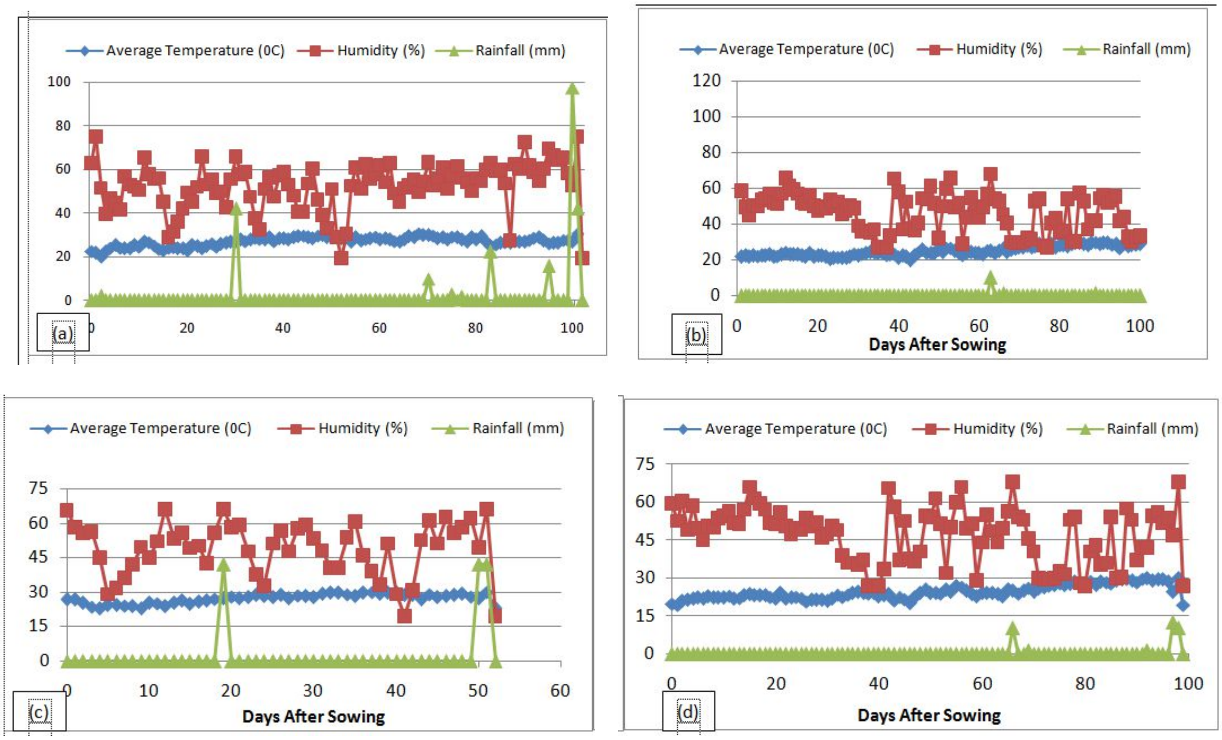

Figure 1: Average Temperature, Humidity (RH) and Rainfall at Field (A, B) and Raised Bed (C, D) During Summer 2012-13 and Summer 2013-14, Respectively at MARS, Dharwad

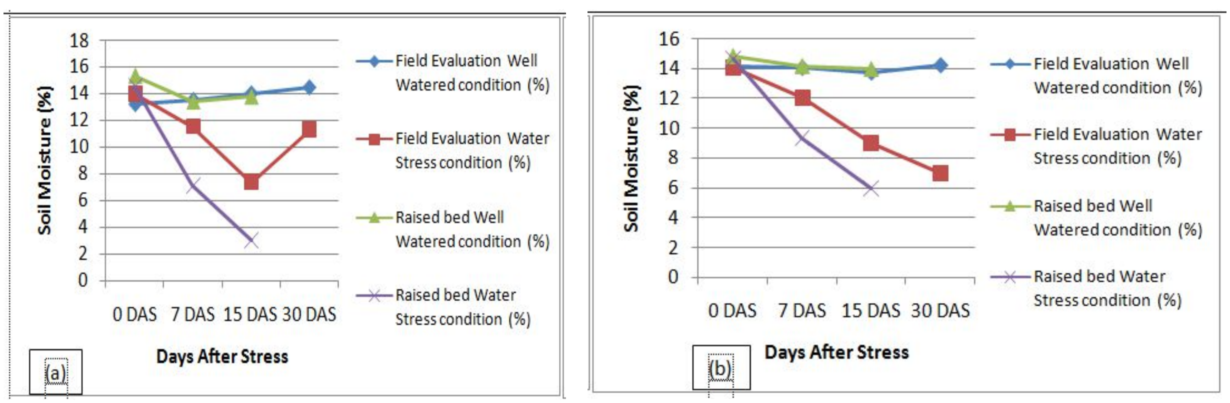

Figure 2: Soil Moisture Content (%) of Two Water Regimes (Well Watered and Water Stress) in Raised Bed and Field Conditions Duringevaluationof Groundnut Rils of TMV-2 X GM 6-1 Cross Over Two Seasons of Summer 2012-13 (A) and Summer 2013-14 (B) at MARS, Dharwad

Table 1: Analysis of Variance for Root Traits in Groundnut Rils of TMV-2 X GM 6-1 Cross Evaluation during Summer2012-13 at MARS, Dharwad

Source of Variation	Root Length (WW)	Root Length (WS)	Root/Shoot Ratio (WW)	Root/Shoot Ratio (WS)	Root Dry Weight (WW)	Root Dry Weight (WS)
Blocks	62.23**	49.1	5.92**	16.25**	0.01	0.02
Entries	93.44**	87.24**	5.03**	7.22**	0.01**	0.03**
Checks	76.20**	61.91**	6.09**	5.56**	0.01**	0.03**
Varieties	92.29**	84.57**	5.01**	7.08**	0.01**	0.02**
Checks * varieties	664.38**	1218.34**	9.32**	70.59**	0.06**	0.03**
Error	16.05	13.23	1.5	0.67	0	0.01
General mean	28.31	26.91	3.81	6.43	0.29	0.36
S.Ed	2.83	0.05	0.87	0.58	0.04	0.05

Table 1: Contd.,

CD 5%	6.12	0.12	1.87	1.25	0.09	0.12
C.V %	10	14.68	22.7	8.99	14.02	14.68

Significance at 1%, * Significance at 5%

Table 2: Analysis of Variance for Root Traits in Groundnut Rils of TMV-2 X GM 6-1 Cross Evaluation during Summer2013-14 At MARS, Dharwad

Source of Variation	DF	Root Length	Root/Shoot Ratio	Root Dry Weight
Replication	1	20.15	0.24	0.01
Genotypes	308	185.06**	1.80**	0.11**
Irrigation Level	1	58259.55**	566.50**	2.59**
Genotypes * Irrigation Level	308	153.77**	0.95**	0.02**
Error	617	31.28	0.2	0.01
Total	1235	147.32	1.24	0.04
General Mean		48.87	2.35	0.45
S.Em		2.796	0.223	0.036
CD 5%		7.77	0.62	0.1
C.V %		11.45	18.98	16.05

** Significance at 1%, * Significance at 5%

Table 3: Pooled Analysis of Variance for Physiological Traits and Pod Yield Per Plant in Groundnut Rils of TMV-2 X GM 6-1 Cross Evaluation Over Both Seasons of Summer2012-13 and 2013-14 At MARS, Dharwad

Source of Variation	Df	RWC At	RWC at 15 DAS	RWC at 30 DAS	SLA at 7 DAS	SLA at 15 DAS	SLA at 30 DAS	SCMR	Pod Yield Per Plant
Season	1	23730.07*	17013.58*	283.293	265.96**	637.57**	12398.98**	58607.43*	128.908**
Genotype	308	20.18**	24.59**	25.47**	73.90**	43.50**	13.42**	25.33**	21.70**
Irrigation level	1	32568.58**	148136.50**	977264.30**	790.44**	27648.30**	47113.11**	17858.65**	18454.59**
Season * Irrigation level	1	29366.5**	20290.39**	5628.14**	1011.53**	1188.82**	6162.22**	1051.31**	228.05**
Season* Genotype	308	20.75**	24.45**	26.05**	78.49**	38.35**	14.34**	26.17**	8.57**
Irrigation Level *	308	21.12**	23.51**	26.90**	76.94**	35.20**	13.99**	27.40**	11.44**
Season * Irrigation	308	19.25**	25.44**	27.93**	87.22**	33.79**	12.83**	24.31**	9.55**
Pooled Error	1234	5.47	9.57	12.99	1.23	2.56	2.18	9.65	0.96
General Mean		81.732	69.248	51.882	62.284	50.118	41.284	44.265	6.147
CD 5%		2.294	3.035	3.536	1.089	1.57	1.447	3.048	0.962
C.V %		2.951	4.467	6.947	1.783	3.194	3.573	7.019	15.961

Significance at 1%, * Significance at 5%

Pooled ANOVA for Physiological Traits and Pod Yield

Pooled ANOVA across the two seasons indicated significant difference between genotypes, seasons, irrigation levels and also their interactions for all physiological traits studied as well as for the pod yield (Table 3).

Variability for Root Traits, Physiological Traits and Pod Yield

Effect of irrigation level was more significant than the effect of season on expression of pod yield per plantduring both the seasons of summer 2012-13 and summer 2013-14 which is indicated through decrease in the mean and range for these traits under WS condition compared to WW condition in both the seasons (Table 4).

In general relative water content (RWC) of leaves was higher in the initial stages of leaf development and declined as the dry matter accumulates and leaf matures. RWC of the RILs under WS condition was lower compared to the

RWC under WW condition as indicated through mean for this trait at different stages of stress. These results were in conformity with the reports of Jain *et al.* 1997. Water stress also decreased the SLA but increased SCMR (Songsri*et al.*, 2009).

Root growth of groundnut is influenced by soil moisture (Jongrungklang*et al.*, 2011). Irrigation level had significant effect on most of the root traits under both seasons. Water stress stimulates the growth of roots into deeper soil even though vegetative growth appears to stop as indicated through increase in the mean of root to shoot ratio under water stress condition.

Correlation of Root Traits and Physiological Traits with Pod Yield

Pod yield per plant under WS condition showed significant positive correlation with root length (0.300**, 0.118** and 0.223**), root to shoot ratio (0.200**, 0.437** and 0.246**), relative water content at 30 DAS (0.631**, 0.496** and 0.532**) and SPAD chlorophyll meter reading (0.664**, 0.331 and 0.441**) while it had significant negative association with per cent reduction in RWC from 15 to 30 DAS (-0.685**, -0.637** and -0.532**), per cent reduction in RWC from 7 to 30 DAS (-0.675**, -0.492** and -0.506**), specific leaf area at 15 DAS (-0.353**, -0.088* and -0.208**) and specific leaf area at 30 DAS (-0.719**, -0.440** and -0.601**) during summer 2012-13, summer 2013-14 and pooled across the two seasons, respectively (Table 5).

Table 4: Mean, Range and Genetic Parameters for Pod Yield per Plant, Physiological Traits and Root Traits in Groundnut Rils of TMV-2 X GM 6-1 Cross Evaluation during Summer2012-13 At MARS, Dharwad

Character	Mean of WW		Mean of WS		Range in WW Condition						Range In WS Condition					
	S 2012-13	S 2013-14	S 2012-13	S 2013-14	S 2012-13			S 2013-14			S 2012-13			S 2013-14		
Pod yield per plant	8.8	8.95	3.95	2.88	0.9	-	19.5	1.4	-	20.8	0.15	-	10.45	0	-	8.6
RWC at 7 DAS	82.51	83.21	82.18	79.06	73.07	-	91.73	74.71	-	93.52	68.56	-	91.8	64.4	-	90.01
RWC at 15 DAS	76.75	77.23	67	56.02	68.02	-	85.06	57.83	-	90.95	55.34	-	74.22	40.61	-	83.06
RWC at 30 DAS	72.16	70.59	30.15	33.85	45.87	-	79.93	61.3	-	80.19	20.23	-	43.07	14.97	-	44.12
SLA at 7 DAS	62.73	63.16	62.55	60.75	49.34	-	71.51	33.61	-	79.11	47.23	-	75.18	48.22	-	73.39
SLA at 15 DAS	53.28	53.65	47.97	45.57	45.46	-	66.99	42.62	-	75.03	40.55	-	58.44	35.83	-	56.97
SLA at 30 DAS	46.31	44.99	40.74	33.1	30.45	-	52.6	30.27	-	60.54	34.81	-	49.6	28.64	-	39.04
SCMR	37.41	45.79	41.43	52.47	21.3	-	46.2	33	-	62.04	28.76	-	54.13	41.82	-	68.57
Root Length	28.31	42.07	26.91	55.73	3	-	65	15	-	82	4	-	57.6	20.5	-	89
Root/Shoot ratio	3.81	1.67	6.43	3.03	0.3	-	17	0	-	4.6	0.9	-	28.18	0.98	-	9.09
Root Dry Weight	0.29	0.4	0.36	0.49	0	-	0.7	0	-	2.27	0.06	-	0.93	0.16	-	3.16

Table 5: Estimates of Phenotypic Correlation Coefficients of Physiological Traits and Root Traits with Pod Yield Per Plant in WS Block during the Two Seasons of Summer 2012-13 and Summer2013-14

Character	Summer 2012-13	Summer 2013-14	Pooled
Root length	0.300**	0.118**	0.223**
Root to shoot ratio	0.200**	0.437**	0.246**
Root Dry Weight	0.03	0.135**	0.016
Relative water content at 7 DAS	-0.047	-0.058	0.002
Relative water content at 15 DAS	-0.006	-0.301**	-0.071*
Relative water content at 30 DAS	0.631**	0.496**	0.532**
Per cent reduction in RWC from 7 to 15 DAS	-0.028	0.245**	0.071*

Per cent reduction in RWC from 15 to 30 DAS	-0.685**	-0.637**	-0.532**
Per cent reduction in RWC from 7 to 30 DAS	-0.675**	-0.492**	-0.506**
Specific leaf area at 7 DAS	-0.012	-0.065	-0.061
Specific leaf area at 15 DAS	-0.353**	-0.088*	-0.208**
Specific leaf area at 30 DAS	-0.719**	-0.440**	-0.601**
SPAD Chlorophyll Meter Reading	0.664**	0.331**	0.441**

Table 6: Estimates of Phenotypic Correlation Coefficients of Physiological Traits and Root Traits with Root Length in WS Block During the Two Seasons of Summer 2012-13 and Summer2013-14

Character	Summer 2012-13	Summer 2013-14	Pooled
Root to shoot ratio	0.448**	0.597**	0.458**
Root Dry Weight	0.074*	0.279	0.105**
Relative water content at 7 DAS	-0.018	0.035	-0.002
Relative water content at 15 DAS	0.028	0.001	0.091*
Relative water content at 30 DAS	0.415**	0.138**	0.289**
Per cent reduction in RWC from 7 to 15 DAS	-0.025	0.016	-0.079*
Per cent reduction in RWC from 15 to 30 DAS	-0.401**	-0.114**	-0.189**
Per cent reduction in RWC from 7 to 30 DAS	-0.399**	-0.116**	-0.264**
Specific leaf area at 7 DAS	-0.012	-0.005	-0.046
Specific leaf area at 15 DAS	-0.243**	0.008	-0.025
Specific leaf area at 30 DAS	-0.369**	-0.180**	-0.331**
SPAD Chlorophyll Meter Reading	0.350**	0.037	0.177**

Pod yield under stress was positively and significantly correlated with RWC and SCMR while significant negative correlation was observed with SLA. Root length was positively correlated with pod yield under stress. Similar to the results of the present study, Jongrungklang*et al*. (2014) also reported significant positive correlations between pod yield and root length at deeper soil layer. Reports of Rucker *et al*. (1995) demonstrating positive correlation of large root systems with pod yield of groundnut grown under drought in field trials was in conformity with the present study.

Correlation of physiological Traits with Root Length

Root length under WS condition showed significant positive correlation with root to shoot ratio (0.448**, 0.597** and 0.245**), root dry weight (0.074, 0.279** and 0.105**), relative water content at 30 DAS (0.415**, 0.138** and 0.289**) and SPAD chlorophyll meter reading (0.350**, 0.037 and 0.177**) while it had significant negative association with per cent reduction in RWC from 7 to 15 DAS (-0.025, 0.016 and -0.179**), per cent reduction in RWC from 15 to 30 DAS (-0.401**, -0.114** and -0.189**), per cent reduction in RWC from 7 to 30 DAS (-0.399**, -0.116** and -0.264**) and specific leaf area at 30 DAS (-0.369**, -0.180** and -0.331**) during summer 2012-13, summer 2013-14 and pooled across the two seasons, respectively (Table 6).

Positive correlation among root characters such as root length and root dry weight was also reported by Painwadee*et al*. (2009). Significant positive correlation of root length was observed with RWC at 30 DAS and SCMR at 30DAS while significant negative correlation with SLA at 15 and 30 DAS in the present study. But in contrast to these results Painwadee*et al*., 2009 reported that physiological and root traits were not correlated which may be due to the different stages of measurement of physiological traits (70 DAS), and root traits where root traits were evaluated at the time of harvest. But in our study, correlations were observed between those physiological traits and root traits which are measured at similar stages (75 days after as sowing).

DISCUSSIONS

Drought is a major cause of the reduction for plant growth and yield in groundnut. Our results showed that intermittent drought resulted in increased root length, root to shoot ratio and root dry weight. Among the physiological traits SLA and SCMR showed positive response towards intermittent drought where as RWC and its derived trait of percent reduction in RWC at critical stages showed negative response.

Reduction in pod yield under intermittent water stress is primarily due to the decrease in the total number of flowers and reduced duration of the pod development phase (Vorasoot*et al*. 2003).Even though, first flush of flowers could not form pegs during stress period, root growth induced during the stress period could assist in maintaining the leaf water content required for reproductive phase by reducing the vegetative growth. This means that the root might enhance partitioning of assimilates to developing pod yield by maintainingroot to shoot ratio under intermittent drought conditions.

Within the RIL population,there is a wide variation exist for reduction in the pod yield when subjected to intermittent drought (Harris et al., 1988).

Further, drought related reduction in growth and yield of plants could be ascribed to stomatal closure in response to low soil moisture, which decreased the intake of CO_2 and, as a result photosynthesis is decreased (Cornic, 2000; Flexas*et al*., 2004).But low SLA genotypes were expected to have greater photosynthetic capacity per unit leaf area (Nageswara Rao *et al*., 1995). Similarly, findings of Nageswara Rao *et al*. (1995) that high SCMR genotypes had greater photosynthetic capacity further strengthened the results of the present study of using high SCMR or low SLA as a selection criterion for enhancing pod yield under drought in groundnut.Similarly, Puangbut*et al*. (2011) also reported that SCMR had moderate correlation with pod yield indicating the possibility of selection for this trait to improve yield.

Similar results were observed that root characteristics were important for drought tolerance in groundnut (Jongrungklong et al., 2011). The main reason due to root growth initiated by the drought stress could maintain both reproductive and pod initiation phase after which, the pod filling is completed. Roots are one of the components among all other components which influence overall performance of groundnut under intermittent drought condition.

CONCLUSIONS

Root length alone may not define the drought tolerance, whereas root length along with root to shoot ratio and other physiological traits such as RWC, SLA and SCMR at severe stress conditions could be effective selection criteria for improving the pod yield in groundnut under intermittent drought conditions where substantial amount of water is left in the subsoil after vegetative phase.

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